SOFT-STALLING CONTROL FOR SMALL WIND TURBINE POWER REGULATION

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Abstract
Wind energy is currently the fastest-growing energy source in the world, with a concurrent growth in demand. This project proposes a new strategy for grid-connected small wind turbines operating in high wind region by soft-stalling control strategy. The proposed method is driven by the rated current/torque limits of the electrical machine and/or the power converter, instead of the rated power of the connected load, which is the limiting factor in other methods. The developed strategy additionally deals with the problem of system start-up preventing the generator from accelerating to an uncontrollable operating point under a high wind speed situation. By using the voltage and currents sensors system start up can be avoided preventing the generator to an uncontrollable high wind speed situation. This method is applied to a small wind turbine system consisting of a permanent magnet synchronous generator (PMSG) and a simple power converter topology.

Keywords: PMSG, BoostConverter, H-Bridge Converter

1.0Introduction

The most widely used converter topology on the generator side for low power grid connected system consist of a Permanent synchronous micro generator, diode rectifier, boost converter, H-bridge inverter, line filter. To interface the generating system with the grid either or a H-bridge converter or the three phase inverter can be used. A special back to back inverter was proposed in order to reduce the number of power components in the passive rectifier plus boost converter plus H-bridge configuration. However the special back to back inverters are more complex control and the need of shaft position sensor. A sensor less controller was developed in order the use of shaft position sensor using such topology.

The controlling and protection under wind high speed regions are one of the biggest challenges in the operation. The turbine must be operated below the maximum efficiency point to prevent damage when the wind power exceeds is turbine power rating. Some breaking mechanism must be enabled if the wind power excess is too high furling control, stall control; pitch control, mechanical brakes and electrical brakes are the proposed methods in order to control the turbine power rating exceeding its maximum rate the electric brake using a lobar to shortcut the generator windings to produce a high braking torque is preferred option for small wind turbine due to its reduced cost & simplicity. However, this method has some drawbacks including a fissional torque in the wind turbine shaft of large current in the generator windings, which can eventually damage the system.

Soft stall methods operate the turbine at a non optimal tip speed ratio in order to decrease the extracted power from the wind. The proposed soft stall methods considered in the high wind speed condition where there is a mismatch between the maximum wind power that can be extracted with the turbine and the load demand. Therefore, the TSR is reduced to make the extracted power equal to load power. The Permanent magnetic synchronous generator if the power converted can produced a torque to contract the torque produced by wind.

2.0 Block Diagram& Description

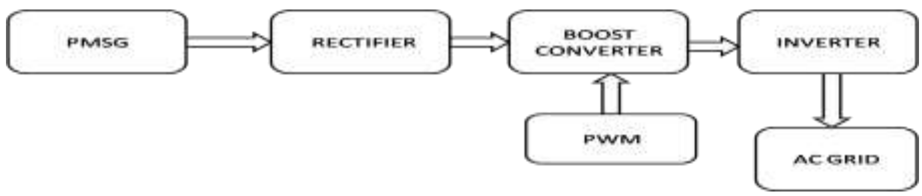


Fig.2.a Block diagram for wind Turbine Control

It deals with the problem of system start up during a high wind speed situation. The soft stall method uses current & voltage sensors only which are typically available in low cost micro wing turbines, a cost effective solution. The soft control method has been implemented on a 2.5kw wind generator system.

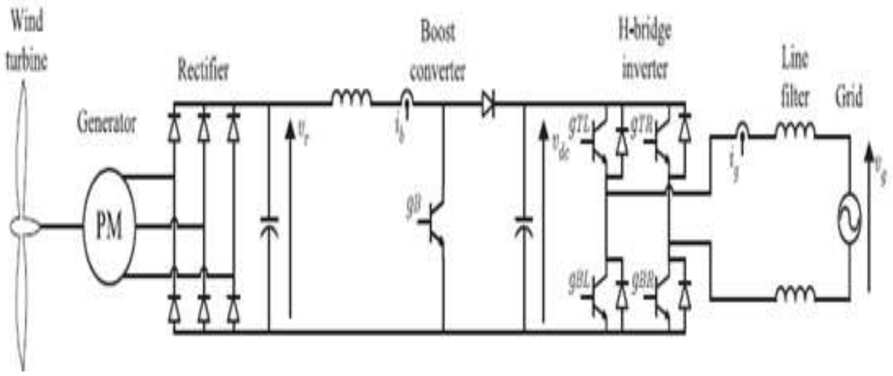


Fig.2.b.Schematic Representation of the wind energy generation system

Permanent magnetic synchronous generator is most economical. They are used to perform the electro mechanical conversion. When the mechanical load increases the output voltage will be decreased.

PGMS is directly coupled to the wind turbine shaft without a gear box. The machine produces a 3-phase voltage , E at no load whose magnitude & frequency change proportionally to the rotor speed of the machine.

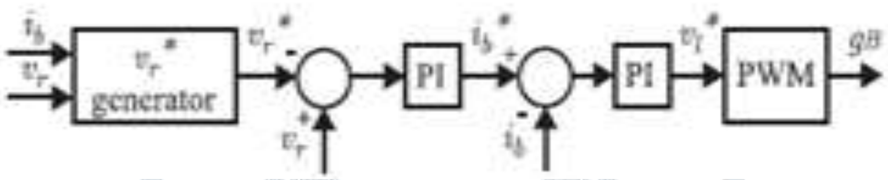


Fig.2.c.Block Diagram for Boost converter control system

The wind turbine speed is controlled by the boost dc/dc converter,which demands the current needed to create the requiredbraking torque in the PMSG. The speed of the turbine is indirectly controlled by imposing a rectifier output voltage, *vr*,according to the characterization described in Section II-B. Thecommand for the rectifier output voltage, *v∗r*, comes from ablock that has been called "*v∗r*generator," as can be seen inFig. 1(b), which includes both MPPT and overspeed protectionalgorithms, as it will be described in Section IV.The rectifier output voltage is controlled using a cascadedcontrol, in which the outer loop controls the rectifier outputvoltage, *vr*, by commanding a boost current command, *i∗b*, to theinner loop controlling the boost converter current. The outputof the current controller is the voltage to be imposed to theboost converter inductance, *v∗l*, which is translated into a dutycommand, *gB*, by a pulse width modulation (PWM) generatorblock. Conventional proportional-integral (PI) controllers (4)are used in both control loops

$$PI(s) = k_p + \frac{k_i}{s}$$

where*kp*is the proportional gain, *ki*is the integral gain, and *s*the Laplace operator. It is noted that the gains differ for eachcontroller.The sign in the rectifier output voltage error calculation inFig. 1(b) is reversed since to increase the rectifier voltage theboost current must be decreased. The boost current controllerhas been tuned to achieve a 500 Hz bandwidth with no overshoot
in the step response. The rectifier output voltage controllerhas been tuned to achieve a bandwidth of only 0.1 Hz with amaximum admissible overshoot of 5% in the step response. Thereason for selecting such a low bandwidth is to approximate therectifier output voltage dynamics to the turbine/generator speeddynamics.

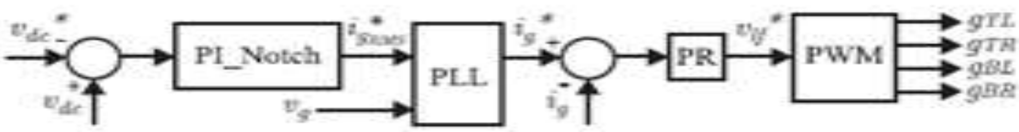


Fig.2.d. Block Diagram of H-Bridge converter control system

In order to inject into the grid, the same amount of energy thatis being extracted from the wind, a power balance is performedin the system through the dc-link voltage. The dc-link voltage,*v*dc, is set to a fixed reference value, *v∗*dc, that can only be keptconstant by injecting the appropriate amount of current to thegrid, *ig*. The dc-link voltage is controlled with a PI controlleraugmented with a notch filter (5), as can be seen in Fig. 1(c)

$$\text{PI\_Notch}(s) = \left(k_p + \frac{k_i}{s}\right) \frac{s^2 + 2\xi_z \omega_n s + \omega_n^2}{s^2 + 2\xi_p \omega_n s + \omega_n^2}$$

Wherekp is the proportional gain, and ki is the integral gain,ξz and ξp are the damping coefficients of the notch filter zerosand poles, respectively, and ωn is the central frequency of thefilter. It is noted that the controller gains are different to the PIcontrollers already described.

The notch filter is used to prevent the controller from rejectingthe necessary dc voltage oscillation required to absorb theinstantaneous power difference between a three-phase system,

the PMSG, and a single-phase grid connection. Otherwise thisoscillation would be translated to the controller output whichis the RMS grid current command, i∗gRMS . The controller has

been tuned to achieve a closed-loop bandwidth of 40 Hz withthe notch filter providing −20 dB of attenuation at 100 Hz (i.e.,single-phase instantaneous power pulsation).In order to achieve unity power factor, the RMS grid currentcommand, i∗gRMS , is synchronized with the grid voltage usinga synchronous phase-locked loop (PLL) algorithm [31], shownin Fig. 1(c). The instantaneous grid current command, i∗g , is injectedinto the grid bymeans of the H-bridge inverter, controlledby a proportional-resonant (PR) controller

$$\text{PR}(s) = k_p + k_r \frac{2 \cdot \omega_r \cdot s}{s^2 + \omega_r^2}$$

Where *kp* and *kr* are the proportional and resonant gains, respectively, and *ωr* is the resonant frequency. The proportional gain has a different value than the controllers previously described.

This type of controller ensures zero tracking error at the resonant frequency which is set to the grid frequency. The controller has been tuned to achieve a closed-loop bandwidth of500 Hz, a worst-case disturbance rejection frequency responseof−30 dB, and a resonant frequency of 50Hz.

3.0SIMULATION AND RESULT

3.1Case-I: **Increasing Wind Condition**

The turbine behavior under increasing wind conditions starting from rest. The wind speed is 10 m/s for 10 s, then it changes to 17 m/s, and at 13 s increases again to 33 m/s. The 17 m/s wind speed exemplifies the case of a wind speed that can be always handled by the generator by temporary surpassing the rated torque/current A wind speed of 33 m/s represents a case that can eventually produce a torque higher than the absolute maximum limit of the turbine. The 10 m/s wind speed makes the turbine to accelerate, making a rectifier voltage command v∗r to be generated by the v∗r minimum generator block Since the rectifier voltage commands larger than the actual voltage, no boost current will be commanded to be drawn from the generator andthe turbine will speed up at a rate only dictated by the turbine torque.

When the rectifier voltage reaches the cut-in voltage (VR MIN= 280 V), the MPPT control block is activated and some current starts to be extracted from the generator. The boost current, ib, and the target MPPT current, imppt, are forced to converge by the MPPT control block, at 10 s, a sudden change of the wind speed from 10 to 17 m/s occurs. Although such wind speed change is not realistic in practice, it is useful to evaluate the control dynamics, and will be used both for simulation and experimental cases. The new wind speed results in a large increase of the turbine torque that must be counteracted by the generator. The required boost current is consequently larger than the rated current and the overspeed control makes the voltage commando decrease to *VR* MIN to reduce the speed, and thus, the turbine torque. This makes to further increase the boost current for a while, in order to produce enough torque to brake the turbine. As it was stated before, the system must be designed to withstand a short time over current. At the end of that transient, the current is again under the rated value. At*t* = 13 s, the wind changes to 33 m/s. Since this wind speed can be above the controllable limits at a relatively low rotor speed, the voltage command is reduced to *VR* SAFE by the proposed method. This is accomplished by the over current block described. After measuring a current above, the rated value for a predefined time the over current flag is activated making the voltage command to decrease.

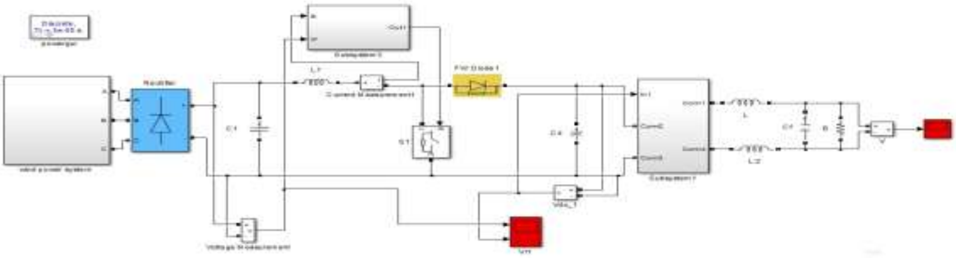


Fig..3.1.a Increasing Wind Circuit Diagram

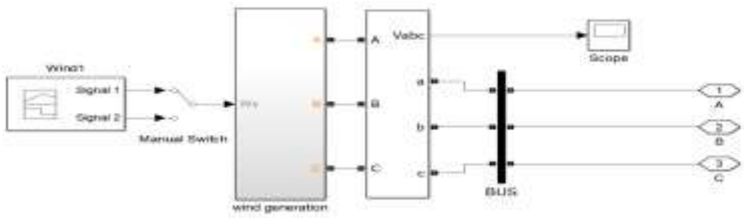


Fig.3.1. b Switch in Increasing Condition

The above circuit diagram shows the function of switch in increasing condition.The switch can be controlled either automatically or manually. Generally it is preferred manually.

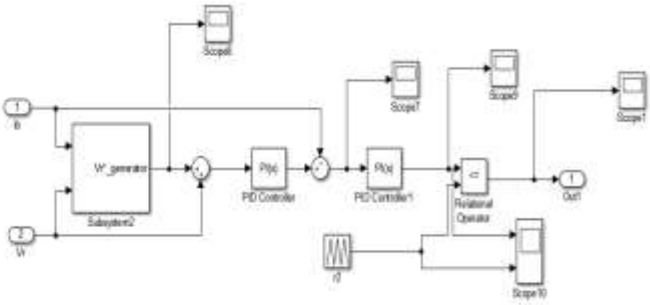


Fig.3.1. c Feed Back System for Controlling the Shaft

The above circuit diagram is used as feedback system for controlling the shaft, in this we compare voltage $V_r$to V^*_r such that it is controlled by the pulse width modulation so that only the required amount of the speed of the shaft is needed

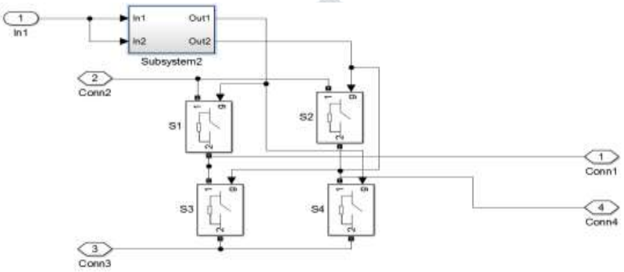


Fig.3.1. d H-Bridge Rectifier

The above circuit diagram shows the circuit of a H-Bridge converter which is used for converting DC voltage in step AC voltage. In this we are using 4 MOSFET's which are show in the above figure to get the required output.

The graph shown below is a graphical representation of the generator torque. The torque is taken on the y-axis and the speed is taken on the x-axis. With the help of this graph we can keep the torque of the generator on a constant line.

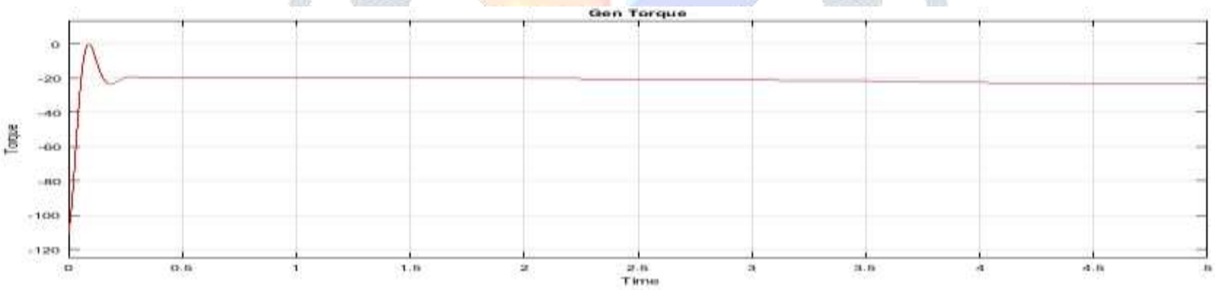


Fig.3.1. e Torque Vs Time

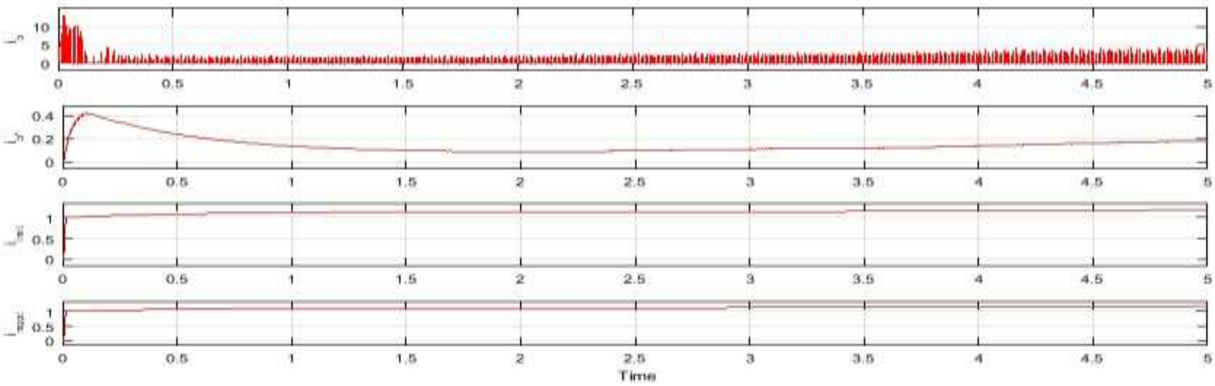


Fig.3.1. f Graphical representation of Current I_b Vs Time

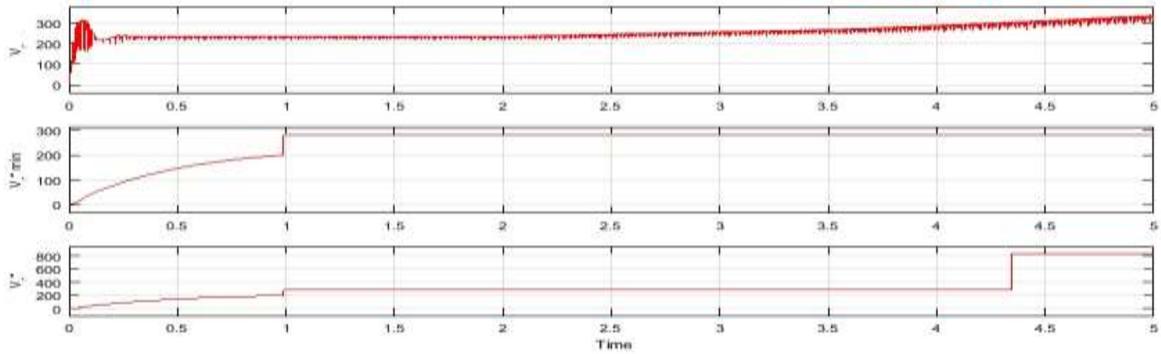


Fig.3.1. i Graphical representation of Voltage V_r Vs Time

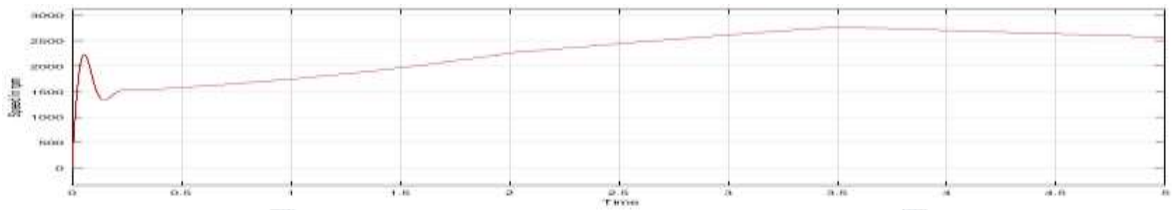


Fig.3.1. j Graphical representation of Speed Vs Time

3.2Case-II Decreasing Wind Conditions

The turbine behavior under decreasing wind conditions starting from rest the wind speed is 30 m/s for 4.5 s, then it changes to 21 m/s, and at 9 decreases to 8.5 m/s. In this case, the 30 and 21 m/s speeds have been chosen as examples of a wind speed that can exceed the generator maximum capabilities, and a wind speed that can be always handled by transitory surpassing the rated torque, respectively. The *y∗r*min generator block detects an increasing voltage from start-up and commands a voltage reference that limits the acceleration of the wind turbine, since a current larger than *i*limitis required to produce the necessary torque the voltage command is held equal to *VR* SAFE once this value is reached. This operating point will prevent the system from repeated start and hard stop cycles, and will keep the generator producing some power at high wind speed.
At t =4.5 s, the wind speed decreases to 21 m/s and the voltage command increases to reach the cut-in voltage (280 V) in which the MPPT mode starts. At that point, the voltage command increases in an attempt to make the boost current, *ib*, to match with the *i*mpptcommand. Since that wind speed can produce torque levels higher than rated torque at some rotor speed in the MPPT range, the system must limit the overcurrent situation. That event is early detected by the proposed method when the actual current surpasses *i*limit, Then the voltage is decreased to *VR* MIN by transiently surpassing the rated current/torque the advantage of the proposed method is that the duration and magnitude of this current transient will be smaller than in case of waiting for the current to surpass the rated value.
The wind speed changes to 8.5 m/s at t = 9 s. The boost current drops since a lower torque is required to maintain the turbine speed/rectifier voltage. Therefore, after some predefined time the overcurrent flag is set to zero and the MPPT control is reactivated. A higher rectifier voltage is then commanded to force to boost current *ib*to follow the MPPT current command *i*mppt, the simulations show that the method works as intended.

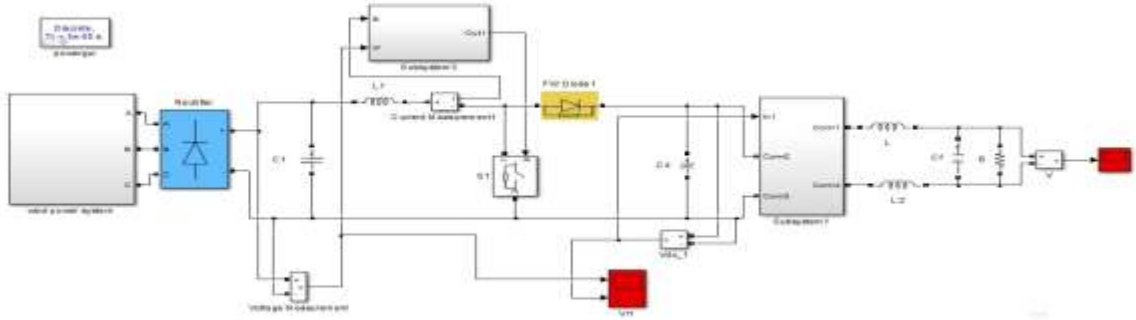
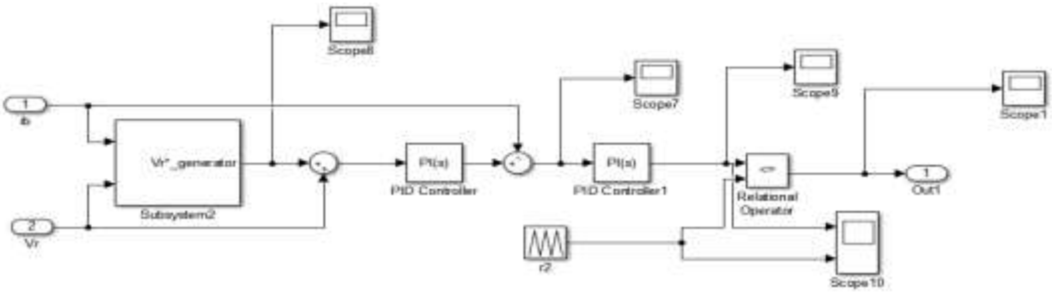


Fig. 3.2. a Decreasing Wind circuit diagram



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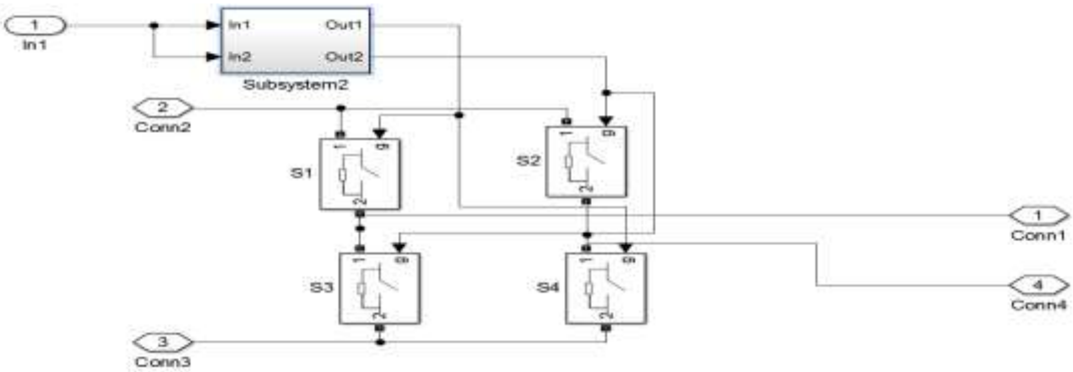

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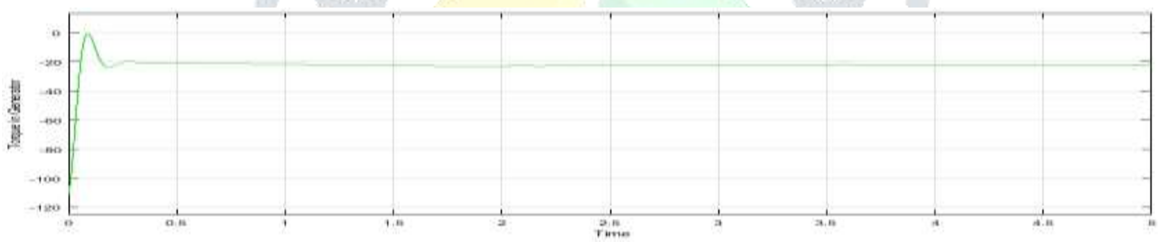

Fig.3.2. e Graphical representation of Torque in Generator Vs Time

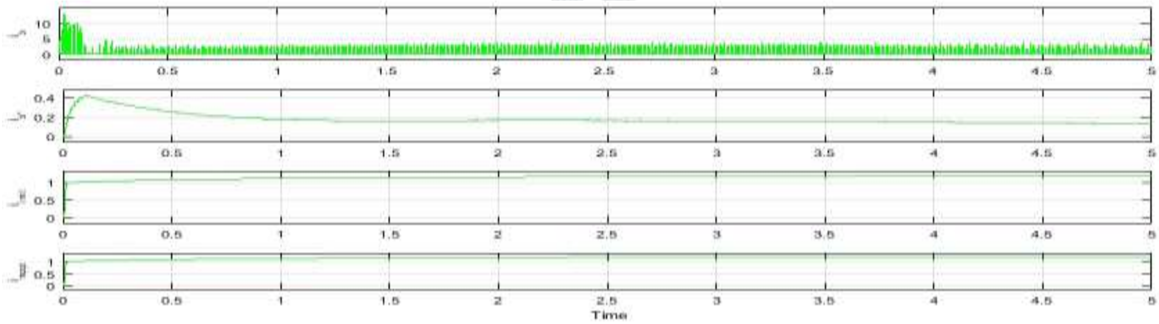

Fig.3.2. f Graphical representation of Current I_b Vs Time

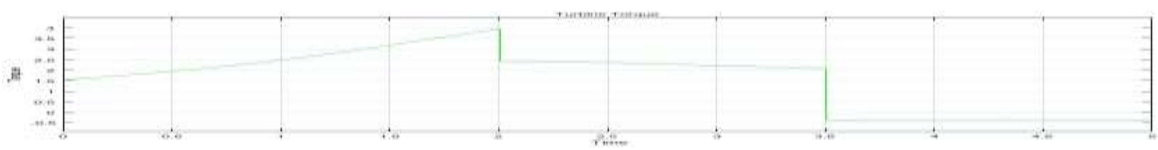

Fig.3.2. h Graphical representation of Turbine Torque Vs Time

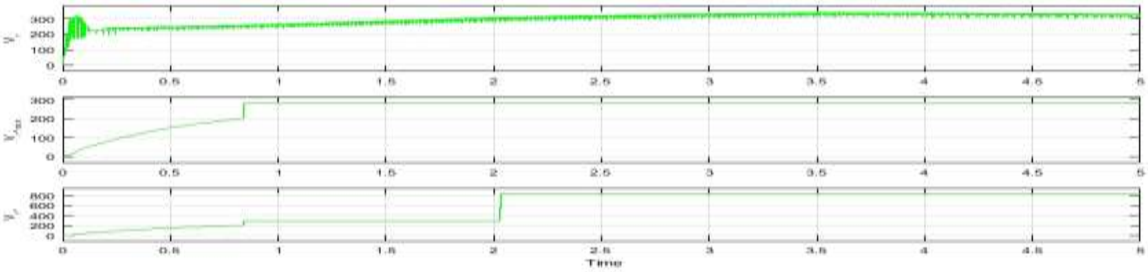

Fig.3.2. i Graphical representation of Voltage V_r Vs Time

CONCLUSION

To test the performance of the proposed method, several simulations for different wind conditions were carried out. PSIM software from Powersim was used for this purpose. The turbine, generator, and boost converter parameters used in simulation were the same as for the actual system, respectively. The power switches for both the boost converterand the H-bridge were modeled as ideal switches, reducing the computational burden. This will lead to slightly better resultsin terms of system efficiency than the actual system, but does not have a significant impact for the analysis presented in thispaper. The switching and sampling frequency are set to 20 kHz in the boost converter and 10 kHz in the H-bridge inverter. The control loops were implemented in a C language function block for easiness of portability to the hardware controller. Two examples including increasing and decreasing wind conditions have been selected to illustrate the behavior of the proposed technique

References

[1] W. Kellogg, M. Nehru, G. Venkatraman, and V. Gerez, "Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems," IEEE Transactions on Energy Conversion, vol. 13, no. 1, pp. 70–75, Mar. 1998.

[2] P. Gipe, Wind Power: Renewable Energy for Home, Farm, and Business, 2nd Edition. Chelsea Green Publishing, Apr. 2004.

[3] A. C. Orrell, H. E. Rhoads-Weaver, L. T. Flowers, M. N. Gagne, B. H. Pro, and N. A. Foster, "2013 Distributed Wind Market Report," Pacific Northwest National Laboratory (PNNL), Richland, WA (US), Tech. Rep., 2014. [Online]. Available: http://www.osti.gov/scitech/biblio/1158500

[4] J. Benjanarasut and B. Neammanee, "The d-, q- axis control technique of single phase grid connected converter for wind turbines with MPPT and anti-islanding protection," in 2011 8th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON). IEEE, May 2011, pp. 649–652.

[5] M. Arifujjaman, "Modeling, simulation and control of grid connected Permanent Magnet Generator (PMG)-based small wind energy conversion system," in Electric Power and Energy Conference (EPEC), 2010 IEEE, Aug. 2010, pp. 1 –6.